On the Sense of Color among some of the Lower Animals.—Part II.

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[Read April 19, 1883.]

In a previous paper which I had the honour of reading before the Society on the 17th November 1881, and which is published in the Journal (xvi. p. 121), I have described some experiments on this subject.

I placed specimens of our common *Daphnia pulex* in a narrow shallow trough, threw upon them lights of various colors, and then at stated intervals counted the number of Daphnias under each color.

A large majority of the Daphnias, though not with the same species, in my experiments preferred the part of the trough on which the green light fell; but on thinking the matter over, it occurred to me that the yellow was perhaps too brilliant.

M. Merejkowski, who has since experimented on the subject, considers that the Daphnias are attracted wherever there is most light, that they are conscious only of the intensity of the light, and that they have no power of distinguishing colors. It is no doubt true that in ordinary diffused daylight the Daphnias generally congregate wherever there is most light. Their eyes are, however, so delicate that one would naturally expect, *à priori*, that there would be a limit to this; and, in fact, direct sunshine is somewhat too strong for their comfort.

For instance, I took a porcelain trough, $7\frac{1}{2}$ inches long, $2\frac{1}{2}$ broad, and 1 deep, and put in it some water containing 50 Daphnias. One half I exposed to direct sunlight and the other I shaded, counting the Daphnias from time to time, and transposing the exposed and shaded halves. The numbers were as follows:—

	In the sun.	In the shade.
At 10.40 A.M.....	4	46
12.50	8	42
1.10	7	43
1.35	7	43
1.50	4	46
2.5	3	47
2.40	4	46
3	5	45
4	7	43
4.30	4	46
	53	447

This seems clearly to show that they avoid the full sunlight.

I believe, then, that in my previous experiments the yellow light was too brilliant for them; and the following experiments seem to show that, when sufficiently diffused, they prefer yellow to white light.

M. Merejkowski, however, denies to the Crustacea any sense of color whatever. His experiments were made with larvæ of *Balanus* and with a marine Copepod, *Dias longiremis*. These, if I understand him correctly, have given identical results. He considers that they perceive all the luminous rays, and can distinguish very slight differences of intensity; but that they do not distinguish between different colors. He sums up his observations as follows:—

"Il résulte de ces expériences que ce qui agit sur les Crustacés, ce n'est point la qualité de la lumière, c'est exclusivement sa quantité. Autrement dit, les Crustacés inférieurs ont la perception de toute onde *lumineuse* et de toutes les différences, même très légères, dans son intensité; mais ils ne sont point capables de distinguer la nature des ondes, de différentes couleurs. Ils distinguent très bien l'intensité des vibrations éthérées, leur amplitude, mais point leur nombre. Il y a donc, dans le mode de perception de la lumière, une grande différence entre les Crustacés inférieurs et l'Homme, et même entre eux et les Fourmis; tandis que nous voyons les différentes couleurs et leurs différentes intensités, les Crustacés inférieurs ne voient qu'une seule couleur dans ses différentes variations d'intensité. Nous percevons des couleurs comme couleurs; ils ne les perçoient que comme lumière"*.

It is by no means easy to decide such a question absolutely; but the subject is of much interest, and I have made some further experiments, which perhaps I may be permitted to lay before the Society.

Prof. Dewar most kindly arranged the apparatus for me again. He prepared a normal diffraction-spectrum, produced by a Rutherfurd grating with 17,000 lines to the inch; the spectrum of the first order was thrown on the trough. In this case the distribution of luminous intensity has been shown to be uniform on each side of the line having the mean wave-length, *i. e.* a little above the line D in the yellowish green.

I placed the centre of the trough at the brightest part of the

* 'Les Crustacés inférieurs distinguent-ils les couleurs?' Par M. C. Merejkowsky.

spectrum, a little, however, if anything, towards the green end. After scattering the Daphnias equably, I left them for five minutes, and then put a piece of blackened cardboard over the brightest part. After five minutes more, there were:—

	At the green end.	In the dark.	At the red end.
Obs. 1.	78	2	20
2.	72	3	25
3.	89	2	9
4.	82	4	14
5.	89	3	8
	410	14	76

Here the two ends of the trough were equally illuminated; but the preference for the green over the red side was very marked.

I then took five porcelain vessels, $7\frac{1}{2}$ inches long, $2\frac{1}{2}$ broad, and 1 deep, and in each I put water containing 50 Daphnias. One half of the water I left uncovered; the other half I covered respectively with an opaque porcelain plate, a solution of aurine (bright yellow), of chlorate of copper (bright green), a piece of red glass, and a piece of blue glass. Every half-hour I counted the Daphnias in each half of every vessel, and then transposed the coverings, so that the half which had been covered was left exposed, and *vice versâ*. I also changed the Daphnias from time to time.

Here, then, in each case the Daphnias had a choice between two kinds of light. It seemed to me that this would be a crucial test, because in every case the colored media act by cutting off certain rays. Thus the aurine owes its yellow color to the fact that it cuts off the violet and blue rays. The light beneath it contains no more yellow rays than elsewhere; but those rays produce the impression of yellow, because the yellow is not neutralized by the violet and blue. In each case, therefore, there was less light in the covered than in the uncovered part.

After every five experiments I added up the numbers of the Daphnias; and the following Table gives 20 such totals, each containing the result of 5 observations, making in all 100.

My reason for adding one vessel in which one half had an opaque cover was to meet the objection that possibly the light might have been too strong for the Daphnias; so that when they went under the sheltered part they did so, not for color, but for shade. I was not very sanguine as to the result of this arrangement, because I had expected that the preference of the Daphnias for light would have overcome their attachment to yellow.

The numbers were as follows:—

Number of Daphnias.

	1. In the		2. In the		3. In the		4. In the		5. In the	
	Opaque.	Uncovered.	Yellow.	Uncovered.	Red.	Uncovered.	Green.	Uncovered.	Blue.	Uncovered.
Feb. 5	126	124	175	75	66	184	83	167	112	138
5	141	109	140	110	97	153	164	86	115	135
6	130	120	191	59	67	183	115	135	100	150
7	102	148	174	76	66	184	87	163	110	140
8	110	140	172	78	76	174	104	146	82	168
8	117	133	183	67	80	170	110	140	94	156
9	92	158	135	115	126	124	116	134	108	142
9	124	126	182	68	120	130	153	97	135	115
10	89	161	126	124	113	137	87	163	57	193
11	126	124	138	112	116	134	127	123	106	144
	1157	1343	1616	884	927	1573	1146	1354	1019	1481
Feb. 11	131	119	153	97	114	136	137	113	91	159
	112	138	164	86	100	150	106	144	78	172
13	106	144	126	124	114	136	139	111	69	181
17	114	136	159	91	118	132	137	113	130	120
18	59	191	133	117	116	134	112	138	102	148
18	54	196	146	104	109	141	126	124	106	144
18	69	181	174	76	75	175	121	129	102	148
18	50	200	146	104	66	184	120	130	95	155
19	99	151	138	112	94	156	114	136	117	133
19	97	153	141	109	95	155	148	102	137	113
	891	1609	1480	1020	1001	1499	1260	1240	1027	1473
Total	2048	2952	3096	1904	1928	3072	2406	2594	2046	2954

The result was very marked. The first two columns show the usual preference for light. If the covered half had been quite dark, no doubt the difference in numbers would have been greater; but a good deal of light found its way into the covered half. Still the result clearly shows that the Daphnias preferred the lighter half. The numbers were 2048 in the dark to 2952 in the light; and it will be seen that the preference for the light was shown, though in different degrees, in almost every series.

The result in the blue gives, I think, no evidence as to color-sense. The numbers were respectively 2046 against 2954, and were therefore practically the same as in the preceding set. Since, however, a certain quantity of light was transmitted through the blue, the result may indicate a want of sensitiveness to the blue rays.

In the red the numbers were 1928 as against 3072.

As regards the yellow, the results were very different, the numbers being, under the yellow 3096, in the uncovered part 1904. Here, therefore, we see a very distinct preference, all the more remarkable because the amount of light was really less than in the uncovered part.

In the green the numbers were much more equal, namely, 2406 against 2594. I do not, however, wish for the moment to draw any conclusion from these last figures, though I give them for what they are worth. The colored medium was, I believe, somewhat too opaque. With a more transparent green, as will be seen subsequently, the result would have been very different.

At any rate the above observations seemed to show a marked preference for yellow. Still I thought it might be objected that, though the Daphnias obviously preferred the uncovered to the shaded half of the vessel, and the yellow to the uncovered half of the vessel, perhaps in the former the uncovered water was rather too bright, and in the latter the shaded part was rather too dark, and that after all the yellow was chosen, not because it was yellow, but because it hit off the happy medium of intensity. The suggestion is very improbable, because the observations were made on several successive, and very different, days, and at very different hours. I also thought that the green was perhaps too dark; I took therefore a lighter tint, and rearranged my little apparatus as follows:—

I placed (March 26) 50 Daphnias in a trough (1), covering over one half of it with a pale green, and another 50 in a

	Trough 1.		Trough 2.		Trough 3.		Trough 4.	
	Green light.	White light.	Yellow light.	White light.	Exposed half.	Darkened half.	Illuminated half.	Unilluminated half.
March 27.								
12.....	35	15	33	17	35	15	28	22
12.25 ...	32	18	28	22	37	13	36	14
12.50 ...	27	23	33	17	36	14	25	25
1.40 ...	33	17	33	17	38	12	30	20
2. 5 ...	26	24	42	8	35	15	26	24
	153	97	169	81	181	69	145	105
2.25 ...	36	14	36	14	26	24	35	15
3 ...	41	9	18	32	24	26	23	27
3.25 ...	31	19	34	16	36	14	35	15
5.15 ...	35	15	25	25	31	19	28	22
5.40 ...	30	20	35	15	32	18	27	23
	173	77	148	102	149	101	148	102
March 28.								
7.30 ...	33	17	34	16	35	15	30	20
7.50 ...	32	18	37	13	27	23	32	18
8.10 ...	34	16	33	17	29	21	30	20
8.35 ...	36	14	35	15	26	24	33	17
9. 5 ...	26	24	27	23	33	17	35	15
	161	89	166	84	150	100	160	90
March 29.								
9.10 ...	36	20	25	25	29	21	32	18
9.25 ...	30	20	27	23	35	15	30	20
9.40 ...	19	31	25	25	29	21	29	21
9.55 ...	20	30	34	16	37	13	29	21
10.30 ...	30	14	34	16	20	30	26	24
	135	115	145	105	150	100	146	104
Total ...	622	378	628	372	630	370	599	401

trough (2) half of which was covered with yellow (aurine). On one side was a similar trough (3), one end of which was shaded by a porcelain plate; and on the other side a fourth trough (4), one end of which had a little, though but little, extra light thrown on it by means of a mirror. As before, I counted the Daphnias from time to time, and turned the troughs round. All four were in a light room, but not actually in direct sunshine. Thus, then, in one trough I had half the water in somewhat green light; in the second trough, half the water in yellow light; in the third, one half was exposed and the other somewhat darkened; while the fourth, on the contrary, gave me a contrast with somewhat more vivid light. If, then, the Daphnias

went under the green and yellow glass, not on account of the color, but for the sake of shade, then in trough 3 a majority of them would have gone under the porcelain plate. On the other hand, if the porcelain plate darkened the water too much, and yet the open water was rather too light for the Daphnias, then in the fourth trough they would of course avoid the illuminated half. The results show that the third trough was unnecessary; still I will give the figures, as the fourth proves that the Daphnias preferred a light somewhat brighter than the ordinary diffused light of the room.

It may be said that perhaps in the previous experiments (p. 208) the red and blue were too dark. I therefore took a very pale solution, and counted the number 20 times for the red and 10 for the blue, placing the yellow in another trough, as before, for comparison. The preference for the yellow was as marked as ever. In the experiments with the red and yellow the numbers were respectively

Trough 1.		Trough 2.	
Under the yellow.	In the uncovered half.	Under the red.	In the uncovered half.
670	330	498	502

When therefore the red solution was sufficiently light the Daphnias were indifferent to it. In the experiments with light blue the numbers were :—

Trough 1.		Trough 2.		Trough 3.	
Under the yellow.	In the uncovered half.	Under the blue.	In the uncovered half.	Under the porcelain plate.	In the uncovered half.
687	313	286	714	336	664

One other possible objection also suggested itself to me. I thought it might be said that the Daphnias went under the yellow and the green not on account of any preference for yellow or green light, but on account of the shelter afforded by the covering. To test this, I covered one half of a trough over with transparent glass, leaving the other uncovered; but after 20 observations I found the number of Daphnias in each half was practically identical. The mere fact of the covering therefore made no difference. On the whole, then, it seems to me that the Daphnias have the power of distinguishing between light of different wave-lengths, and that they prefer the light which we call

yellow and green. Whether it actually appears to them as it does to us is of course another and a more difficult question—one, moreover, not yet solved even for the higher animals. Nor would I necessarily claim for them any æsthetic sense of beauty; but it must be remembered that they feed on minute algæ and other minute vegetables, the prevalent colors of which are yellow, yellowish green, and green. There is therefore nothing improbable, *à priori*, but rather the reverse, in their preference for these colors.

It will be observed that though in these vessels the Daphnias made their preference unmistakable, there were always a certain number in the least popular part. This is natural, because as the position of the light half was reversed every observation, the Daphnias had to swim across the vessel, and some naturally did not find their way to the favourite part. Then, again, in any considerable numbers of Daphnias some are changing, or have recently changed, their skin, and are therefore more or less inactive. Moreover, in pure water the desire for food must often overpower any preference for one color over another. To such causes as these we must, I think, attribute the presence of so many Daphnias in the first vessel at the opaque end, and in the second in the uncovered part.

Still, it was of course not impossible that the presence, for instance, of a certain number under the red and blue was due to a difference of taste, that though the majority preferred yellow, there might be some preferring blue or red. To test this I tried the following experiment. I placed, as before, 50 Daphnias in three of the vessels, covering one half of one with the yellow, of a second with blue, and the third with red. I then from time to time, at intervals of not less than half an hour, removed those which were in the uncovered part and replaced them with an equal number of fresh ones. If, then, some Daphnias preferred red or blue, I ought thus to eliminate the others, and gradually to get together 50 agreeing in this taste. This, however, was not the case. In the first experiment, an hour after the Daphnias were placed in the vessels there were, out of 50, 41 under the yellow, 16 under the red, and 15 under the blue, the remaining 9, 34, and 35 respectively being in the uncovered portions. These, then, I removed and replaced by others. After doing this five times, and thus adding 80 in the yellow division, 187 in the red, and 209 in the blue, the numbers were 37 under the yellow, 15 under the red, and 6 under the blue.

In the second experiment, the numbers after the first hour were 32 under the yellow, 10 under the red, and 11 under the blue. After five observations, during which 86 were added to the yellow division, 188 to the red, and 180 to the blue, the numbers were—under the yellow 35, red 11, blue 15.

In the third experiment, the numbers after half an hour were 40 under the yellow, 14 under the red, and 8 under the blue. After five observations, during which 73 were added to the yellow, 186 to the red, and 206 to the blue, there were—under the yellow 43, under the red 15, and under the blue 7.

In the fourth experiment, the numbers, after half an hour, were 38 under the yellow, 15 under the red, and 14 under the blue. After six observations, during which 89 were added to the yellow, 166 to the red, and 176 to the blue, the numbers were—under the yellow 30, under the red 19, and under the blue 10.

In the fifth experiment the numbers, after half an hour, were 40 under the yellow, 14 under the red, and 13 under the blue. After 7 observations, during which 86 were added to the yellow, 263 to the red, and 272 to the blue, the numbers were—under the yellow 38, under the red 13, and under the blue 15.

	Yellow.	Red.	Blue.
1st observation.			
At the beginning	41	16	15
„ end.....	37	15	6
2nd observation.			
At the beginning	32	10	11
„ end.....	35	11	15
3rd observation.			
At the beginning	40	14	8
„ end.....	43	15	7
4th observation.			
At the beginning	38	15	14
„ end.....	30	19	10
5th observation.			
At the beginning	40	14	13
„ end.....	38	13	15

I conclude, then, that the presence of some of the Daphnias in the red, blue, and violet is more or less due to the causes above indicated, and not to any individual preference for those colors.

My experiments, I think, show that, while the Daphnias prefer light to darkness, there is a certain maximum of brilliancy beyond which the light becomes inconveniently bright to them, and that they can distinguish between light of different wave-lengths.

I suppose it would be impossible to prove that they actually perceive colors; but to suggest that the rays of various wave-lengths produce on their eyes a different impression other than that of color, is to propose an entirely novel hypothesis.

At any rate, I think I have shown that they do distinguish between rays of different wave-lengths, and prefer those which to our eyes appear green and yellow.

The Asteroidea of H.M.S. 'Challenger' Expedition.—Part II.

By W. Percy Sladen, F.L.S., F.G.S.

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Family Astropectinidæ.

Subfamily Porcellanasteridæ.

Rays five, more or less produced. Marginal plates in superior and inferior series, thin, lamelliform, apparently naked, or covered only by an extremely thin epidermal tissue. Abactinal area covered with membrane, beset with simple spiniferous spicules or pseudo-paxillæ, which occupy the whole or only a limited portion of the area. A central epiproctal prominence, more or less defined, frequently developed into an elongate tubular prolongation. Actinal interradial areas more or less extensive, paved with thin squamiform ventral plates, more or less regularly disposed and covered with delicate membrane. Adambulacral plates elongate, simple, bearing spines (one to five in number) on the furrow-margin only; or may have one or more series of small papilliform granules on the outer part of the plate. Cribriform organs along the vertical sutures of the marginal plates in the interbrachial angles. Ambulacral sucker-feet in simple pairs, with conical pointed tips. Madreporiform body placed close to the marginal plates.